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TIME-OF-FLIGHT TECHNIQUE FOR INVESTIGATION OF AMORPHOUS CHALCOGENIDES AND BARRIER STRUCTURES ON THEIR BASE

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It is shown that time – of – flight technique is an efficient method in the investigation of non-crystalline chalcogenide and barrier structures.

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The reliability of any electronic device depends on quality of contact between metal and semiconductor. For crystalline semiconductors a contact phenomenon is studied well. For unordered semiconductors as distinct from crystalline ones so far there is no unified theory of formation of metal - unordered semiconductor contact. Therefore investigations of unordered semiconductors and barrier structures on their base are actual scientific and applied problem.

The modified time-of-flight technique is worked out specially for unordered semiconductors like as amorphous chalcogenides and amorphous hydrogenated silicon. The traditional time-of-flight drift-mobility technique measures time during the carriers transit through sample [1]. The modified time-of flight technique measures charge-collection (G) and electrical field distribution $F_i(x)$ in space charge region of the structure metal - amorphous chalcogenide. Method of internal field profile measurement which uses varies the excitation wavelength and apply of reverse field is described [2 - 4].

Conditions for calculations and measurements are as follows:

1. Carriers are generated by the pulse of monochromatic light and distributed in accordance with the light absorption law.

2. Photogenerated charge is small so it does not affect the internal field distribution, i.e.

$Q_0 \ll \frac{\epsilon\epsilon_0}{d} \int_0^d F_i(x) dx$. Satisfaction of this condition may be tested experimentally from independence G from Q_0 .

3. The external electric field is subtracted from the internal field, i.e. structure is illuminated by pulse of light after apply of reverse field but before redistribution of internal field. Time of delay between apply of reverse field and pulse of light is $RC < t_{del} < t_{rel}$, where RC is the time constant of measuring equipment, t_{rel} is Maxwell relaxation time. Satisfaction of this condition may be tested experimentally from independence G from t_{del} .

4. The influence of surface states in calculations doesn't take in account.

5. Only one type of carriers (electrons or holes) is considered depending on polarity of applied voltage.

6. The work function from metal more than ones from amorphous chalcogenide, i.e. there is depletion layer of semiconductor.

7. The experimental samples are sandwich-type structure with transparent for excitation light electrodes (Fig. 1).

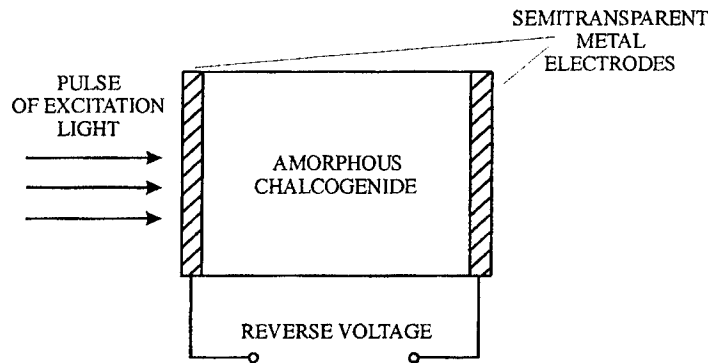


Fig. 1. The experimental sample is sandwich-type structure with semitransparent metal electrodes.

The main idea of the method is contained in compensation of internal field of depletion layer of amorphous chalcogenide - metal contact by external pulse of voltage. The value of the internal electric field is determined by external voltage $V_{G(V,\alpha)}$ under which $G(V, \alpha) = 0$ under certain excitation wavelength (α is absorption efficiency, α is function of wavelength).

$$F_i(x_c) = \frac{V_{G(V,\alpha)=0}}{d}, \quad (1)$$

where d is the sample thickness [3].

Charge collection G is function of absorption efficiency α and external voltage V . We suggest the following equation for defining the charge-collection:

$$G(V,\alpha) = \frac{(1-R(V,\alpha))\alpha\mu\tau}{(1-\exp(-\alpha d))d} \int_0^d \frac{\exp(-\alpha x_g)}{x_c - x_g} \int_{x_g}^{x_c} (F_i(x) + \frac{V}{d}) dx \left[1 - \exp \left(- \frac{d}{\mu\tau \frac{1}{x_c - x_g} \int_{x_g}^{x_c} (F_i(x) + \frac{V}{d}) dx} \right) \right] dx_g \quad (2)$$

where μ is drift mobility of the carriers, τ is the lifetime of carriers, $R(V, \alpha)$ is the coefficient, which take into consideration diffusion of the carriers against field, x_c is the co-ordinate of stop drift (in co-ordinate x_c external field compensate internal field so that resultant field $F_i(x_c) + \frac{V}{d} = 0$), and x_g is the co-ordinate of carriers photogeneration.

$$R(V,\alpha) \geq (1 + \frac{\alpha\phi_T}{F_i(0) + V/d})^{-1}, \quad (3)$$

where ϕ_T is the thermal potential:

$$\phi_T = kT/e, \quad (4)$$

where k is Boltzmann constant, T is absolute temperature, e is charge of electron [3].

Equation (2) as distinct from analogous [3] takes into account the deep trapping by localized states during photogenerated charge drift. This permit to calculate the co-ordinate x_c and the internal field profile with the more accuracy than in [3].

The co-ordinate x_c is defined by absorption efficiency and sample thickness, so that x_c is a function of α and d . In order to get the analytical dependence x_c from α and d it is necessary to solve the equation (2) under the condition that $G(V, \alpha) = 0$. Solution of equation (2) reduces to next integral:

$$\int_0^d \exp(-\alpha x_g) (x_c - x_g) \left[1 - \exp \left(- \frac{d}{|x_c - x_g|} \right) \right] dx_g = 0. \quad (5)$$

Solution of integral (5) permit to obtain the final equation:

$$x_c \left[1 - \exp\left(-\frac{d}{x_c}\right) \right] = \exp(-\alpha d)(d - x_c) \left[1 - \exp\left(-\frac{d}{d - x_c}\right) \right]. \quad (6)$$

The dependence of absorption efficiency from excitation wavelength is measured experimentally for specific structure. Equation (6) is solved by numerical method. These permit to obtain the internal field profile of depletion layer (Fig. 3) and charge-collection directly from experiment.

The time-of-flight technique is limited by half the sample thickness (Fig. 2):

$$\lim_{\alpha \rightarrow 0} x_c = d/2. \quad (7)$$

If depletion layer thickness more than a half of sample ones it is necessary to illuminate back side of sample for obtaining internal field profile. This technique is also limited by surface. The experimental results become inaccurate under light absorption depth less than 50 nm because of carrier recombination on the surface states [2].

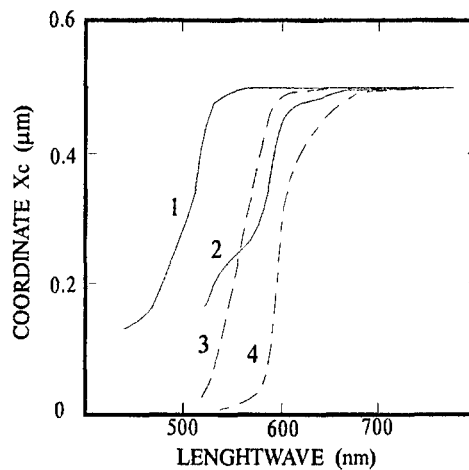


Fig. 2. The x_c (the co-ordinate of stop drift) is calculated for Schottky-barrier in a-silicon (curves 1 and 3) and for a-Si:H p-i-n structure (curves 2 and 4). Thickness of both samples is 1 μm . Curves 1 and 2 are calculated by method of Juska G. [3]; 3 and 4 – are obtained for same samples accordingly by formula (6).

These data allow to calculate the value of $\mu\tau$, potential profile (Fig. 4) and distribution of the density localized states in mobility gap $N(E)$. So it permits to obtain important parameters, which characterize electrical properties of material and efficiency of devices on its base.

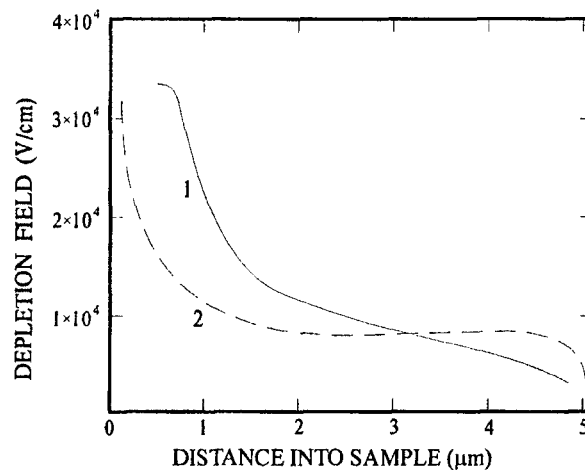


Fig. 3. The profiles of internal depletion field in a-Si:H solar cell (p-i-n structure). Thickness of sample is 5.1 μm . 1 – is measured by Juska G. [3], 2 – is calculated by formulas (1) and (6).

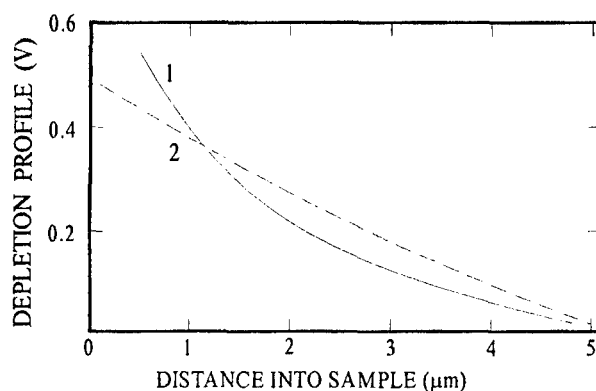


Fig. 4. The depletion profiles in a-Si:H solar cell (p-i-n structure). Thickness of sample is 5.1 μm . 1 – is calculated by Juska G. [3], 2 – is obtained by integration of the internal depletion field $F_i(x)$ (Fig. 3, curve 2).

The suggested modified time-of-flight technique allows to measure $\mu\tau$ for electrons and holes the changing polarity of the applied voltage. Equation (2) as distinct from the analogous [3] takes into account photogenerated charge deep trapping during its drift by localized states. It permits to measure internal field profile and to calculate potential profile and distribution of the density localized states in mobility gap with the more accuracy than previous methods. It is shown that our results differ from data obtained in [2 - 4] (Fig. 2 – Fig. 4) and agree with the theory described in [5, 6] quite well.

With the described modifications the time-of-flight technique becomes a good and effective instrument for investigation of amorphous chalcogenides and barrier structure on their base. The technique allows to reveal the process of formation of barrier at the contact between the metal and the disordered semiconductor.

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